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Report prepared by: Herman P. Schwan Date: 5/31/63

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CONTRACTOR: University of Pennsylvania

PRINCIPAL INVESTIGATOR: Herman P. Schwan

Assistants: Antharvedi Anne and Lawrence D. Sher

TITLE OF PROJECT: Non-Thermal Effects of Alternating Electrical Fields on Biological Structures.

Objectives: To investigate experimentally and theoretically non-thermal effects of alternating electrical fields on biological structures.

ABSTRACT (OR SUMMARY) OF RESULTS:

a. Since start of project:

See annual reports for 1952 through 1961.

b. During current report period:

1) A theory of "pearl-chain formation", describing, from fundamental physical principles, the process whereby small particles align under the influence of an alternating electrical field, was developed and reported in 1961. It treated two cases by methods which, although difficult, were virtually exact:

(a) Perfectly conducting particles suspended in a perfect dielectric fluid;

(b) Perfect dielectric particles suspended in a perfect dielectric fluid.

The goal in these theoretical studies was to give an expression for the threshold field strength for pearl-chain formation in order to evaluate its biological significance. Also, an approximate solution, assuming a dipole-dipole interaction between the two spheres in the theoretical model was

developed to give the threshold field strength in a convenient, closed form for case (b). Comparison of exact and approximate theoretical solutions for this case showed agreement within the expected experimental error. The development of a similar approximate solution for the most general case:

(c) Particles and suspending fluid characterized by arbitrary dielectric constants and conductivities,

had to await the development of a theoretical expression for the electrical potential energy which enters into the Boltzmann Principle as applied to the two-particle model of pearl-chain formation. This expression was derived near the end of 1961.

An approximate solution for the general case (c), again assuming a dipole-dipole interaction, has not been developed. Although there is no exact theoretical solution available with which to assess the validity of the approximation, it may be expected to have an error which is not greater than the comparable approximation in case (b).

Experimental measurements have been made of the threshold field strength for pearl-chain formation in cases (b) and (c). Agreement with the theory is within the experimental error inherent in these measurements.

A theory has also been developed to describe the field strength necessary to cause orientation of a single spheroidal particle with the direction of the applied field. Theoretically it is expected that for a given suspension of uniform spheroidal particles, the ratio of the threshold for pearl-chain formation to that for orientation should be almost completely determined by the eccentricity of the particle. Experimental verification of this prediction has been obtained. Orientation occurs first, then pearl-chain formation, as the field strength is increased.

2) A manuscript, "Electrical Properties of the Membranes of the Pleuroneumonia-like Organism A 5969", has been prepared and published in the Biophysical Journal. It reports on the impedance studies of the PPL-Organism mentioned in the previous summary.

3) A manuscript entitled, "A Model for Pearl Chain Formation: (1) Two perfectly conducting spheres", has been prepared. It summarizes our previous work on phase (a), item 1, mentioned above.

DETAILED PROGRESS REPORT

1. Theoretical and experimental studies on pearl-chain formation and orientation:

These studies have been submitted and accepted as a doctoral thesis by L. D. Sher under the title, "Mechanical Effects of AC Fields on Particles Dispersed in a Liquid; Biological Implications." Copies of this thesis will be submitted as technical report No. 37.

2. Electrical Properties of the Membranes of the Pleuropneumonia-like Organism A 5969:

Details of this work, published in the Biophysical Journal, Vol. 2, Number 5, pp. 395 - 407, September 1962 are being submitted in the form of reprints as Technical Report No. 35.

3. Theoretical and experimental studies of the scattering and absorption of microwave energy from lossy dielectric objects.

Health hazards, resulting from the exposure of mankind to strong sources of non-ionizing electromagnetic radiation, have been discussed by several investigators. The harmful effects of excessive amounts of radiation either result from a general rise in total body temperature or are limited to selective temperature rises of sensitive pars of the body such as the eye. Present indications are that the effects of such radiation are caused solely by the heat resulting from the absorbed energy. It has been assumed, in the case of total body irradiation, that a fever corresponding to a temperature rise greater than $1^{\circ}C$ is intolerable. Eye cataracts are produced when the eye temperature elevation is of the order of $10^{\circ}C$. It thus appears that significant body temperature rise is the serious hazard whenever substantial parts of the body are exposed so that conditions of total body irradiation are approximated. Based on this concept Schwan recommended a tolerance dosage of 10 milliwatts per square centimeter of total body absorption for the frequency range of interest to mankind. If one wishes to interpret this tolerance dosage in terms of the free field values of power density, which is easily measured, the absorption properties of mankind should be known.

Schwan and Li have calculated the percentage of airborne radiation that is absorbed by the human body, on the assumption that the body extremities could be ignored and the trunk of the body could be approximated by a three layer infinite plane slab made up of skin, subcutaneous fat and deep tissue such as muscle. They found that percentage of absorbed energy may vary from 20 to 100 percent depending on frequency, fat thickness and skin thickness.

This work has been primarily supported by the Air Force. However, since 1961 funds from ONR have been used exclusively for this project. A detailed report, including both ONR and Air Force supported phases, will be submitted as Technical Report No. 36. These studies have been submitted and accepted as a doctoral thesis by A. Anne under the title, "Scattering and Absorption of Microwaves by Dissipative Dielectric Objects: The Biological Significance and Hazards to Mankind"

The object of Report No. 36 is to study theoretically and experimentally the effects of body curvature and size and its extremities on the percentage of airborne energy that is absorbed by mankind.

PLANS FOR FUTURE

Further experimental work about the threshold of "pearl-chain formation" will be conducted. Experimental work concerned with the time required for "pearl-chain formation" is also planned. The possibility of reorienting or rearranging macro molecular constituents by pulsed fields will be considered.

CURRENT REPORTS AND PUBLICATIONS

1. "Electrical Properties of the Membranes of the Pleuropneumonia-like Organism A 5969", Herman P. Schwan and Harold J. Morowitz, Biophysical Journal, Volume 2, Number 5, September 1962, Technical Report No. 35.

2. "Mechanical Effects of AC Fields on Particles Dispersed in a Liquid; Biological Implications". Thesis of Lawrence D. Sher, The Moore School of Electrical Engineering, University of Pennsylvania, 1963. Technical Report No. 37.

3. "Scattering and Absorption of Microwaves by Dissipative Dielectric Objects: The Biological Significance and Hazards to Mankind". Thesis of Antharvedi Anne, The Moore School of Electrical Engineering, University of Pennsylvania, 1963. Technical Report No. 36.

4. "A Model for Pearl-Chain Formation : (1) Two Perfectly Conducting Spheres". To be submitted shortly.